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### Solid Waste Management at Florida Technological University

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SOLID WASTE MANAGEMENT  
AT  
FLORIDA TECHNOLOGICAL UNIVERSITY

BY  
ROBERT F. HEVER

A Research Report Presented in Partial Fulfillment  
of the Requirements for the Degree  
Master of Science in Environmental Systems Management

FLORIDA TECHNOLOGICAL UNIVERSITY

May 1972

## PREFACE

This paper is a report on a study of the management of solid wastes at Florida Technological University (FTU). This study endeavors to provide a basis for effective planning for disposal of FTU's solid wastes, both in the next few years and at the time of maximum FTU population. Essentially, the study affirms that the present system of refuse collection by a private contractor is the best method of disposal, with the possibility that recycling of mixed paper may become feasible at some future time.

The author acknowledges the patient guidance and generous technical assistance provided by Dr. Martin P. Wanielista, the Committee Chairman, and the constructive criticism offered by Committee Members Dr. Thomas Edwards and Dr. William F. Smith. Others who provided valuable assistance are: Dr. Waldron M. McLellon, Chairman of Department of Civil Engineering and Environmental Sciences and Professor of Engineering; Dr. John R. Bolte, Assistant Dean for Academic Affairs; and Fred E. Clayton, Director of Physical Plant. Last of all, the author would like to express appreciation to his wife for her excellent typing and helpful criticism of the draft.



## TABLE OF CONTENTS

PREFACE.....	iii
I. INTRODUCTION.....	1
Need for the Study	
Objective	
Summary of Recommendations	
II. BACKGROUND.....	4
FTU Population	
Quantity Generated at FTU	
III. POSSIBLE SOLID WASTE SYSTEMS.....	9
Recycling	
Incineration	
Pyrolysis	
Composting	
Sanitary Landfill	
Milling	
Compacting and Baling	
Open Dumps	
Ocean Disposal	
IV. EVALUATION OF SYSTEMS FOR FTU.....	28
General	
Recycling at FTU	
Incineration at FTU	
Composting at FTU	
Sanitary Landfill at FTU	
Milling at FTU	
Compacting and Baling at FTU	
Combination Systems at FTU	
V. SUMMARY AND CONCLUSIONS.....	49
Recommendations	
Future Needs	
APPENDIX .....	52
SOURCES CONSULTED.....	59

## INTRODUCTION

Every year, the average American throws out a ton of trash, and the amount is increasing (1). The technology of solid waste collection and disposal has not kept up with the upsurge of population. Even the creation of 120-foot-high "mountains" from sanitary landfills, compacted and covered with gravel and clay and used for recreation, has not been sufficient to cope with the 5½ pounds of trash that the average American disposes of daily. About 90 percent of the wastes collected go to some 12,000 land disposal sites (2). Chicago, New York, and other cities are running out of space for more landfills. The disposal of solid wastes is a serious problem facing many American cities. Small communities might take note of the disposal problem now facing the cities, and by careful planning, avoid having to face similar situations. FTU is such a community, and the management of FTU solid waste is the subject of this report.

In this study, the removal of usable materials from refuse (solid wastes) and the sale of those materials for re-use is termed "recycling." Technically, it is salvaging; but the process has been called recycling in general usage, and this study will use the generally accepted word "recycling" rather than the technically correct "salvaging."





It is also recommended that a study determine the break-even price for mixed paper recycling and that the recycling be implemented when that price is approached.

It is further recommended that a study determine whether there is a suitable on-campus site for a sanitary landfill.

## II. BACKGROUND

### FTU POPULATION

The current make-up of FTU solid wastes is about 90 percent (by weight) paper (4), with the remainder being plastics, wood, leather, rubber, textiles, metals, and food waste (garbage). The make-up of solid wastes at FTU may be typical of universities, but it is far from typical for the nation. A breakdown of typical solid waste is shown in Table 1 on the following page. Typical municipal solid waste has 10 percent (by weight) ashes, 5 percent leaves, and 10 percent garbage; estimated comparable figures for FTU are 0, nil, and less than 4 percent, respectively. The most significant difference, however, is that municipal solid wastes have 42 percent paper, whereas FTU has 90 percent.

The maximum amount of solid wastes generated at FTU can be approximated by multiplying the anticipated maximum FTU population (students, faculty, and staff) by the estimated average rate of solid waste generation per FTU capita at the time of peak campus population.

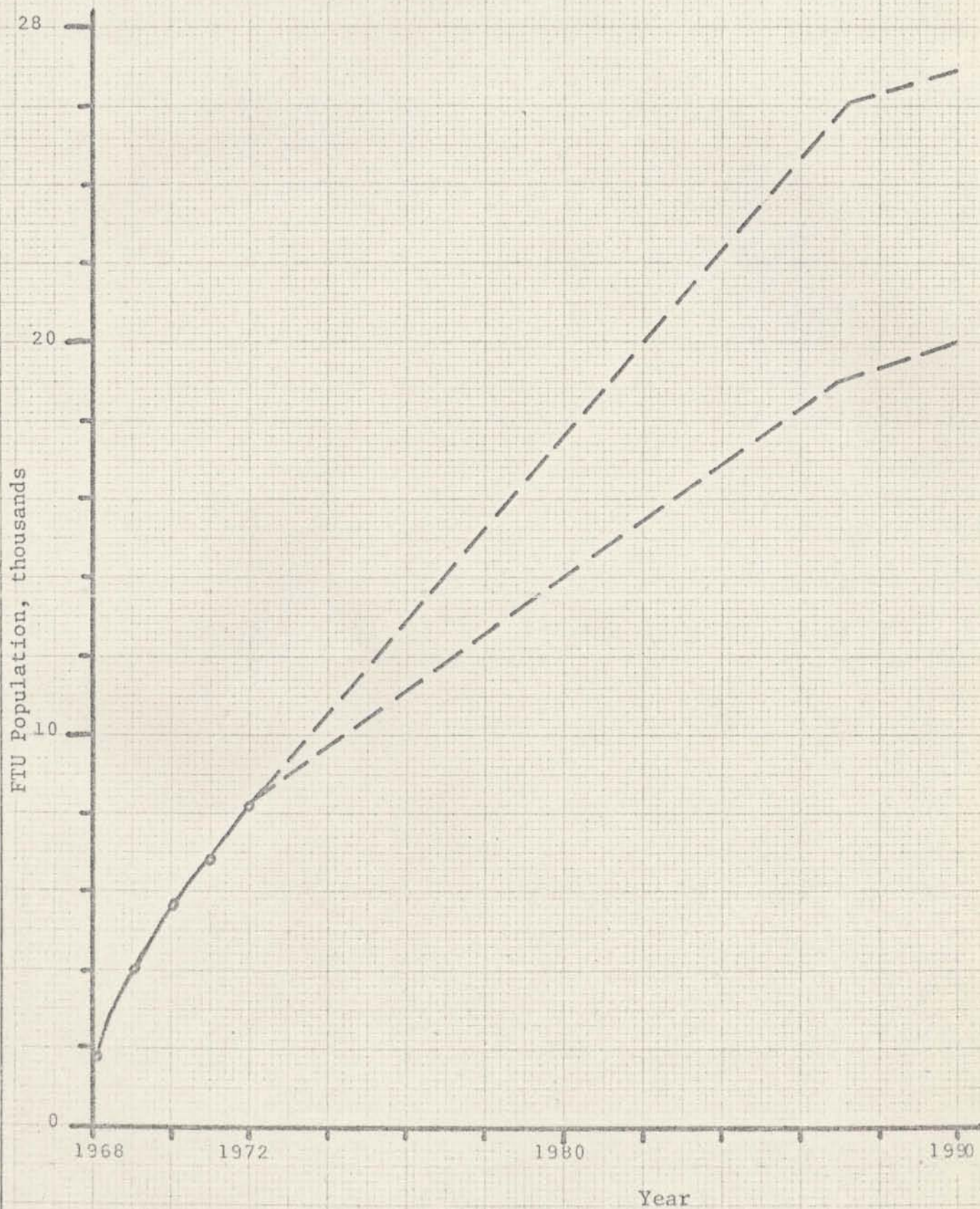
A graph of FTU population since 1968 (see Figure 1) indicates an essentially constant annual growth rate of approximately 1400 students and 75 faculty (staff growth rate not available). The curve shows no indication of levelling-off in the future. A 1970 estimate by the East Central Florida Regional Planning Council puts the FTU student population of 27,040 by 1990 (5). However, population estimates for FTU, including those made by FTU, have been declining in



TABLE 1--COMPOSITION AND ANALYSIS OF AVERAGE  
MUNICIPAL REFUSE  
(from studies made by Purdue University)(6)

<u>Component</u>	<u>Percent of all refuse by weight</u>	
Paper . . . . .	42.0	} Rubbish, 64%
Wood . . . . .	2.4	
Grass . . . . .	4.0	
Brush . . . . .	1.5	
Greens . . . . .	1.5	
Leaves . . . . .	5.0	
Leather . . . . .	0.3	
Rubber . . . . .	0.6	
Plastics . . . . .	0.7	
Oils, paints . . . . .	0.8	
Linoleum . . . . .	0.1	
Rags . . . . .	0.6	
Street sweepings . . . . .	3.0	
Dirt . . . . .	1.0	
Unclassified . . . . .	0.5	} Food Wastes, 12%
Garbage . . . . .	10.0	
Fats . . . . .	2.0	
Metals . . . . .	8.0	
Glass and ceramics . . . . .	6.0	} Noncombustibles, 24%
Ashes . . . . .	10.0	
All Refuse . . . . .	100 %	Composite Refuse, as received

FIGURE 1--FTU POPULATION GROWTH





the past two years. Dr. John R. Bolte (3), Assistant Dean for Academic Affairs at FTU, estimates the maximum FTU full-time-equivalent (FTE) student population to be " . . . about 20,000 to 22,000 sometime after 1982; maybe 1990." Taking the median figure plus-or-minus a 15 percent contingency, adding faculty at a 1:18 ratio (faculty:FTE) (3), and adding staff at a 1:16 ratio (staff:FTE) gives a maximum FTU population of between 20,000 and 27,000.

#### QUANTITY GENERATED AT FTU

Data from a 1971 report by three FTU engineering students (4) and from the collection agency for campus refuse (7) indicates that FTU currently generates approximately 3.2 million pounds of paper per year, and paper represents 90 percent by weight of all FTU solid waste. Thus the average amount of solid wastes generated at FTU is about 395 lb/year/capita. An FTU population of 20,000 to 27,000 would result in 3950 to 5330 tons/year of solid wastes generated at FTU.

The percentage of paper in solid wastes in the United States has been increasing since about 1954 and the trend is expected to continue. It is estimated that between 1963 and 1980 the consumption of paper will increase 40 percent per capita (8). However, much of this increase will be the result of even greater usage of paper products for packaging, especially food packaging. The make-up of FTU paper consumption is such that no significant increase is expected as a result of the national trend to use more paper per capita in the future. At FTU, an estimated 10 percent of the paper is newspaper, and 90 percent is mixed paper (tablet paper, computer runs, cardboard,



and other paper products); very little of FTU paper waste is from food packaging.

Of the possible systems of solid waste disposal, nine were selected for consideration at FTU. Each of the nine is discussed in the next section.

### III. POSSIBLE SOLID WASTE SYSTEMS

Nine solid waste systems will be considered for implementation for the FTU environment. These nine are commonly considered to be practical from a cost standpoint, and would be feasible alternatives to the current system of disposal by a private contractor.

#### RECYCLING

The term "recycling" technically includes salvage, reclamation, and by-product recovery. Salvage is the removal of usable materials from refuse and the sale of those components for re-use. By-product recovery involves making new materials out of the usable portions of the refuse. The amounts of salvage and by-product recovery depend upon the composition of refuse. An estimate puts 30 percent of refuse as salvageable, with 70 percent available for by-product recovery (9).

The salvage industry has about 2300 companies that make \$4 to \$7 billion per year from the sale of paper, metals, glass, and rubber. The annual salvage of paper is about 11 million tons, which represents approximately 20 percent of annual requirements for paper fiber. However, the percentage of paper salvaged is decreasing because of economic considerations (9).

The volume of scrap iron salvaged yearly is usually about 50 percent of the total production of steel. Prices for ferrous scrap salvage are subject to wide fluctuations. In 1971, 70 million tons of



scrap iron were salvaged for an average of \$33 per ton. In 1968, the price was \$24 per ton; in 1970, \$55 per ton (9).

Scrap dealers successfully recycle lead, copper, tin, zinc, and aluminum. Relatively high prices for copper and tin ensure a fairly complete salvage of those materials. The amount of lead salvaged annually is about 200 percent of domestic production from virgin ore. The annual aluminum salvaged represents 25 percent of domestic requirements (9). Whenever there is sufficient demand, the salvage of materials is assured because demand will increase the market price.

Salvaged glass, or cullet, provides only 5 to 10 percent of the raw materials in glass manufacturing. Glass requires much grading, by type and color, and the demand is very low.

In spite of the concern in recent years for recycling, the market for salvaged goods is generally decreasing, and salvage companies are slowly being forced out of business. One reason is that virgin ores receive preferential treatment on freight rates (set by the federal government), a carry-over from the early days of industrial expansion in the United States. A reassessment of freight rates and the introduction of tax incentives for the secondary (scrap) materials industry are in order. However, significant improvement for the industry can be expected only when the demand for salvaged material increases. More efficient sorting of solid wastes only increases the supply of materials that are already in surplus.

The recycling efforts of neighborhood recycling enthusiasts account for only a small amount of the total solid wastes generated.



In 1970, one major aluminum company recycled 80 million aluminum cans, but the total aluminum cans produced that year were 62 billion (9).

Recycling efforts may only increase inventories of secondary (scrap) materials that are already surplus. When such materials cannot be sold, they frequently end up in a landfill. The key to reclamation and recycling is the ability of industry to accept and use secondary materials in their processes. Until recycling becomes widespread, much of the secondary materials will continue to constitute a problem in solid waste disposal.

#### INCINERATION

Incineration is a means of reducing the volume of refuse. An efficient incinerator will reduce volume by roughly 95 percent, better than the reduction of most other methods (10). A portion of the refuse is converted into stack gases (which include fly ash); the remainder is solid residue that still presents a disposal problem. To minimize air pollution, the fly ash in the gases must be removed. This is often done with a wet scrubber. The scrubber water and water used for quenching the residue contain suspended solids and dissolved substances. This water must be treated (by filtration, settling, chemicals, etc.) and cooled before discharge into the environment.

Some incinerators have been designed to utilize the heat released by the process for power generation. Incinerator heat is provided by a low sulfur fuel that gives 3000 to up to 7000 BTU per lb. (10), with indications that the heat content will increase in the future as the percentage of paper and plastics in refuse increases.

About 700 tons per day of refuse from Frankfurt, Germany, is incinerated to provide light and heat for 40,000 people. Fly ash is trapped by electrostatic precipitators. National Geographic (11) reports that--as of December of 1970--"more than 15 cities in Europe, Japan, and North America use similar installations."

Incinerators, however, are one of the most expensive systems of refuse disposal. The cost of building all types of incinerators is high. Operating costs can be \$12 per ton (12). Incinerators emit smoke and odors. The installation of air pollution control devices increases both the capital and operating costs of the units. Further, poor burnout reduces the effectiveness of the installation. A national survey of community solid waste practices in 1968 (13) revealed that about 75 percent of incinerator operations were "inadequate," mostly because poor operator technique resulted in inefficient incinerator operation. Even with a 95 percent reduction in volume, there still remains a residue problem, plus the solids in the water used in the process.

Incineration has major advantages:

It reduces refuse volume by as much as 95 percent.

The residue is inert, precluding the health hazards of rodents, flies, mosquitoes, and leaching.

It releases energy that can be tapped for power.

Its stack gases, although they include fly ash, do not pollute the atmosphere with most of the products of fossil-fuel combustion.

It uses much less land for disposal than landfills.



It is not directly affected by climate or unusual weather.

It can be centrally located where the solid waste is generated. A carefully operated plant on well landscaped grounds is acceptable in neighborhoods that would not tolerate other disposal methods.

The disadvantages are also significant:

Incinerators require a large capital investment. The increasing concern with air pollution is requiring higher performance standards. Meeting these standards usually adds to the capital cost.

Operating costs are relatively high.

Economic justification of incineration often depends on a strategic site location, such as a densely populated area. The attendant heavy truck traffic may be a significant nuisance and hazard to the area.

Incineration leaves residue that must be disposed of.

Incineration costs are high in comparison with most other methods of solid waste disposal. In 1969, most central incineration plants (as opposed to on-site incinerators in hotels, supermarkets, etc.) cost between \$6000 and \$12,000 per ton of daily rated capacity to build (capital costs), excluding the cost of land, and operating costs were reported to range between \$3 and \$7 per ton processed (8).

#### PYROLYSIS

Pyrolysis is incineration in a high-temperature environment free of oxygen. Pyrolysis, an outgrowth of charcoal production, gives a highly processable residue and reduces the volume of refuse by a



claimed 94 percent. It uses supplemental fuel, and has a disadvantage of high operating cost (9).

Pyrolysis of 500 tons of refuse per day costs about \$6 per ton. The products of the process, including oil, gas, and char residue, have a net heat value of 8 million BTU per ton of refuse (9). The process must be part of a larger system involving milling, pyrolyzing, and residue processing--all done in series.

### COMPOSTING

Composting is an aerobic, bacteriological degradation of the organic portions of refuse. The end product is usable as a soil conditioner although often not saleable because of competition from a variety of commercial general-purpose and specialized fertilizers and soil conditioners. A composting system usually includes manual sorting of the refuse, size reduction, magnetic separation of ferrous materials, digestion (two to five days) in an aerated reactor, aging, and regrinding.

Composting has not been very successful in the United States as a method of recycling organic waste material. In India, where the government supports an intensive program to utilize all organic wastes on farmland, composting has been widely used. A major disadvantage of composting is the cost of handling and sorting the refuse. As previously mentioned, there is usually no ready large-scale market for the fertilizer produced by composting plants. (Lack of markets caused 20 compost plants to close in the U.S. in the 1950's and 1960's.) (9) Also, odors and open storage are an aesthetic problem.

Composting is a simple process, and it can be very useful where high levels of organic waste are available, as in canneries and slaughterhouses.

The cost of composting varies from \$2.50 to \$20 per ton of refuse processed. This wide range is the result of differences in plant size, methods of operation, number of plant personnel and prevailing wage rates, number of shifts, accounting systems, financing details, land costs, and degree of success in disposing of the product. For the composting of municipal solid wastes in favorable locations, for 300 tons per day, capital and operating expenditures range from \$1 to \$10 per ton of refuse processed, with a probable figure of \$8/ton. Corresponding costs for 50 tons/day are \$4 to \$20/ton with a probable cost of \$12/ton (14).

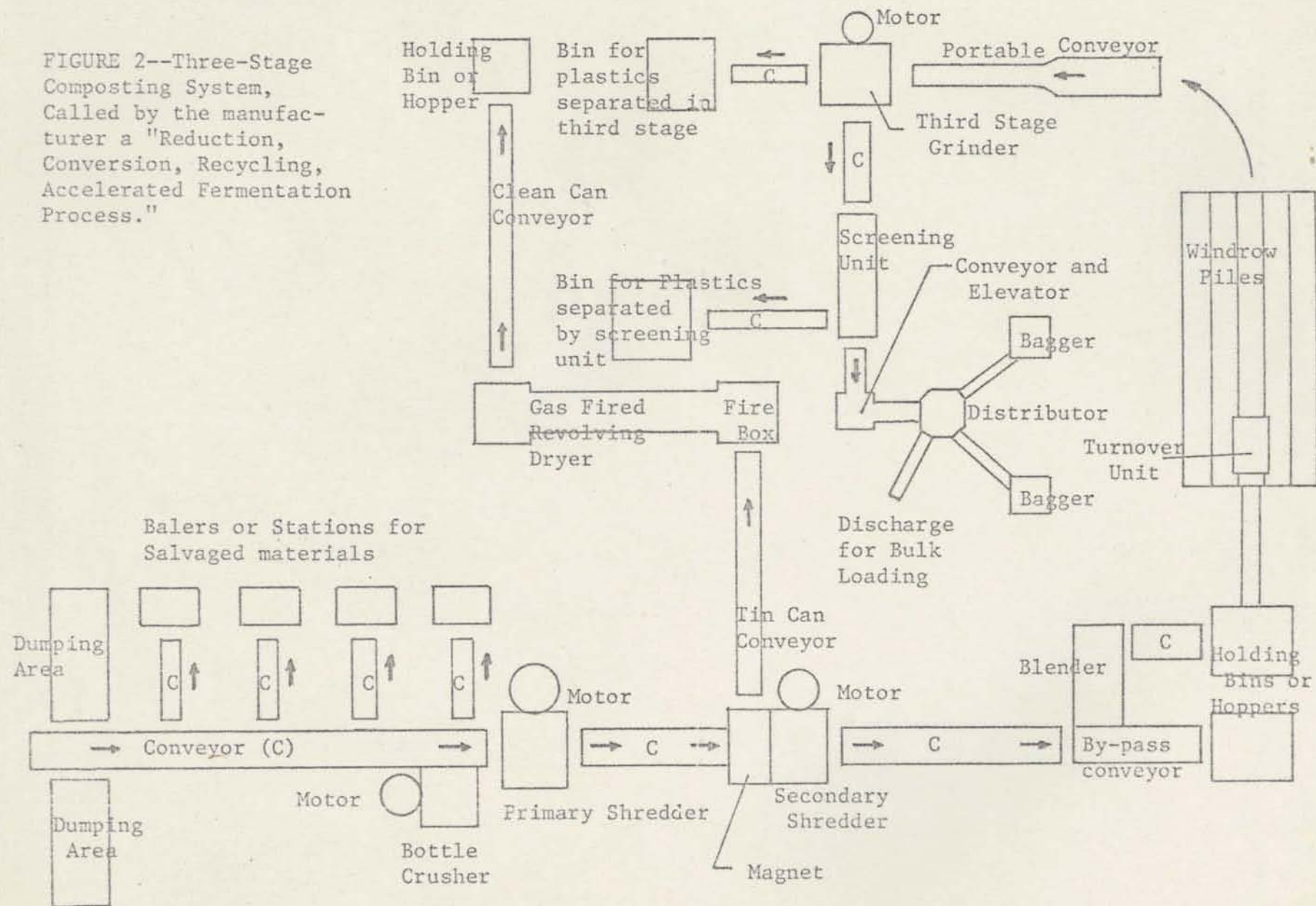
One quote on the cost of a large municipal composting system (400 to 500 tons per 8 to 10-hour day) is \$1,428,086, excluding land but including equipment, buildings, erection, and working capital needed for the first year. A slightly smaller unit (250 to 300 tons per day) is being operated by the city of Mobile, Alabama (15). The schematic diagram for such a composting system is shown in Figure 2.

#### SANITARY LANDFILL

Sanitary landfill is a cheap method of solid waste disposal. Total costs are about 75¢ to \$4 per ton, excluding land (12), with the lower figure being applicable to landfills that are marginal, i.e., being close to open dumps in their mode of operation. The average total operating cost plus amortized capital cost of acceptable sanitary



FIGURE 2--Three-Stage Composting System, Called by the manufacturer a "Reduction, Conversion, Recycling, Accelerated Fermentation Process."



Source: Gruendler Crusher and Pulverizer Co.



landfills is approximately \$1.05 per ton (13). Operating costs for Texas sanitary landfills have ranged between \$0.44 and \$1.92 per ton (16). The wide variance of costs is due to differences in the cost of labor and to differences in hauling costs.

[Sanitary landfill requires land that is relatively high and dry, availability at the site of a large volume of cover earth, and preferably a site location that is not near residences. The amount of land required is about one acre per year for each 10,000 persons, for refuse compacted to a depth of seven feet (16).>

[Acceptable practice at a sanitary landfill requires that the solid wastes be compacted and covered with a 6-inch layer of earth at the conclusion of each day's operation, or more frequently during the day if possible. The site must have provisions for leaching, and burning is not permitted. Observance of these restrictions precludes the nuisance and health hazards associated with open dumps: air and water pollution; stationary and blowing litter; odors, rats, flies, and mosquitoes; explosions; etc.)

In a sanitary landfill that is properly operated, at least six inches of compacted cover is provided at the close of operations each day. When the fill is completed, a minimum of two feet of compacted cover is necessary. Adult flies cannot pass through 2-5/8 inches of compacted soil. A minimum of two feet of compacted cover aids in controlling rats (16).

[In order that a landfill site not be a source of environmental pollution, certain geological and hydrological factors must be considered:

- 1) the slope, topography, and drainage of the site
- 2) the permeability and water-holding capacity of the soil
- 3) the depth and variation in position of the water table, and the rate of water transmission.

Generally, the sites that are most geologically and hydrologically secure for landfills are those with soils that are mostly clays and muds with low permeability, located in level to slightly depressed areas.)

The dollar value of a site may appreciate a substantial amount as a result of the landfilling process providing an increase in elevation. A low area, difficult to utilize, may become a valuable site for a park or golf course. The landfill operating agency may therefore be able to lease or purchase the substandard land for a low price, recognizing that the landfilling operation will increase the value of the site significantly. The cost of site acquisition can be shared by the solid waste disposal agency and the park and recreation agency when the site is intended to become a recreation area. This type of cooperation can be very profitable to a community since it allows acquisition of a landfill site at low cost while also providing a site for future recreational areas.

Completed sanitary landfill sites can also be used for green belt areas (to serve as a buffer zone between potential residential developments, for example), for agricultural fields, or even for cemeteries. The use of completed sanitary landfills for buildings is not recommended. The fill is very poor material for foundations. If building construction is planned, islands of selected solid-fill



material can be incorporated into the landfill. Otherwise, buildings must be constructed on pilings or caissons to carry the load through the landfill.)

(Settlement will occur in a landfill, the rate depending largely on the amount of moisture present in the fill. As fill ages, the material anaerobically decomposes and the total mass is reduced as it is converted to carbon dioxide and methane gases which escape through the fill. Also, decomposition reduces the supporting strength of the fill, and voids collapse, producing settlement. Settlement can cause the surface of the fill to become concave, allowing rain water to collect and then seep into the fill. This additional moisture, centralized under the low point of the fill surface, causes increased settlement. The total amount of settlement in a landfill will depend on the depth of refuse, the amount of compaction, and the composition of the waste. Most of the settlement will occur within the first year, with complete settlement usually being accomplished within two years.) Most fills will settle between 10 and 30 percent (13).

(A sanitary landfill, regardless of size, must have suitable land; access roads; fencing; lights; equipment to excavate, cover, and compact the solid waste; and personnel to operate the equipment. The major expenditure is for buying, maintaining, and operating the equipment.) One means of reducing these costs for a small community is through the operation of a joint or regional sanitary landfill, with two or more towns sharing the costs. To avoid having the site cease functioning as a sanitary landfill during periods of major breakdowns of the equipment, spare or "float" equipment may be obtained ahead of



time. Again, the cost of float equipment may be prohibitive for a single small community, but shared purchase by several towns may be feasible. Another solution is to have float equipment provided--when needed--by the county.

#### MILLING

This process, also called "grinding," "shredding," and "pulverizing," is a European concept that is gaining acceptance in the United States as a means of reducing the volume of solid wastes and utilizing the concept of sanitary landfills without some of the disadvantages. The process consists of transporting the refuse to a milling plant where it is reduced in volume by about 45 percent. This is accomplished by dozens of hammers, of about 15 pounds each, that beat the refuse against grates and reduce it to particles measuring 3 inches or less, depending on the size of grate used (17). Refuse that cannot be ground small enough to pass through the grates is ejected up a chimney and out of the mill ballistically by the impact of the hammers. Both the ejected items and the pulverized refuse are discharged onto a conveyor which transports them to a compactor. The load is then transported to a landfill or incinerator. (See Figure 3 for a typical arrangement of equipment and Figure 4 for photograph of equipment in operation.)

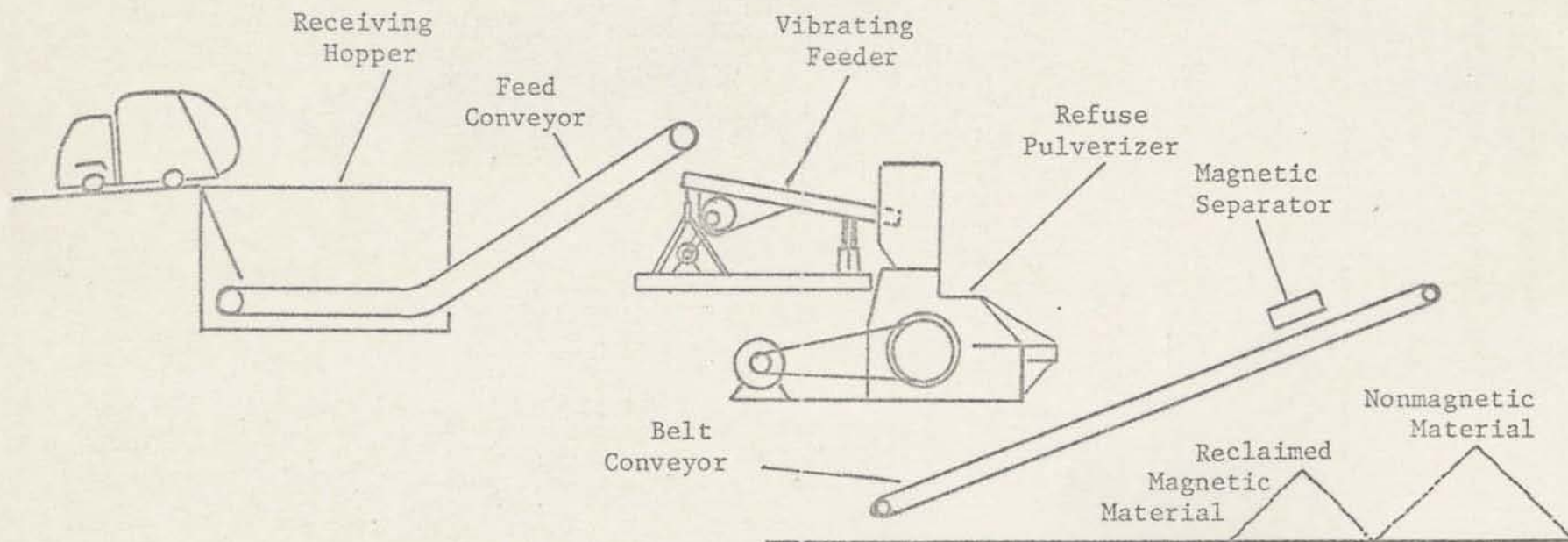
Milled refuse has many advantages as a landfill material

Milled refuse presents no odor problems.

Blowing paper, plastic, and other debris is not a problem.

Milled refuse will not support a flame or propagate combustion.

FIGURE 3--A TYPICAL REFUSE PULVERIZER SYSTEM



Source: Jeffrey Manufacturing Company, Bulletin 1125.



FIGURE 4--SHREDDERS IN OPERATION.  
Model in center is probably Eidal's  
"Maxi" with a capacity of 20 tons  
of steel per hour. Maxi can convert  
a car body into fist-size nuggets in  
only 40 seconds.



Source: Eidal International Corp.



Insects and rodents are not a problem with milled refuse.

Voids and nesting places are eliminated in the fill site.

It is not obnoxious to look at. Nearby, it looks like shredded paper; at a distance, it looks nondescript.

(Figure 5 shows refuse before and after milling.)

A daily cover of earth is unnecessary. This, plus the increased density of milled refuse, can produce a savings of 35 to 50 percent in space at the landfill.

Milled refuse will support loaded hauling equipment, even in wet weather.

Milled material compacts more easily, permitting shaping and contouring.

A disadvantage of milling for small communities is that the process is not practical for low tonnages. Also the initial investment is high. For example, Brevard County, with a total population of 230,000 (18) plans to spend \$3.1 million on its central shredding and milling facility and another \$2.4 million to complete its total waste disposal system (sanitary landfill). The shredder is expected to cost about \$400,000 (19). In addition to the costs of basic equipment, money must be expended for backup provisions--as with any process involving mechanical equipment. Not everything can be milled: tree logs, large branches, furniture, rugs, and similar items must be handled separately. Another problem at present is the inclination of regulatory agencies to insist on a daily land cover--as for a sanitary landfill. Although shredding will increase the life of a sanitary

FIGURE 5--REFUSE BEFORE AND AFTER MILLING



Source: Eidal International Corp.



landfill by reducing the volume of the solid wastes before they are applied, it is more expensive on a yearly basis than landfilling alone.

#### COMPACTING AND BALING

(Compaction reduces the volume of solid waste material by about 30 percent while the material is being transported inside a compactor truck. Upon release, the solid waste returns to near its original volume. Compaction may also be used to reduce on-site storage space required for solid waste materials. (The home compactor is an example of this.) Compaction ratios of 5:1 are easily attained for on-site compaction units.)

Total costs for high volume (224,000 tons per year) compaction and baling are about \$0.90/ton and \$0.07/ton, respectively (9).

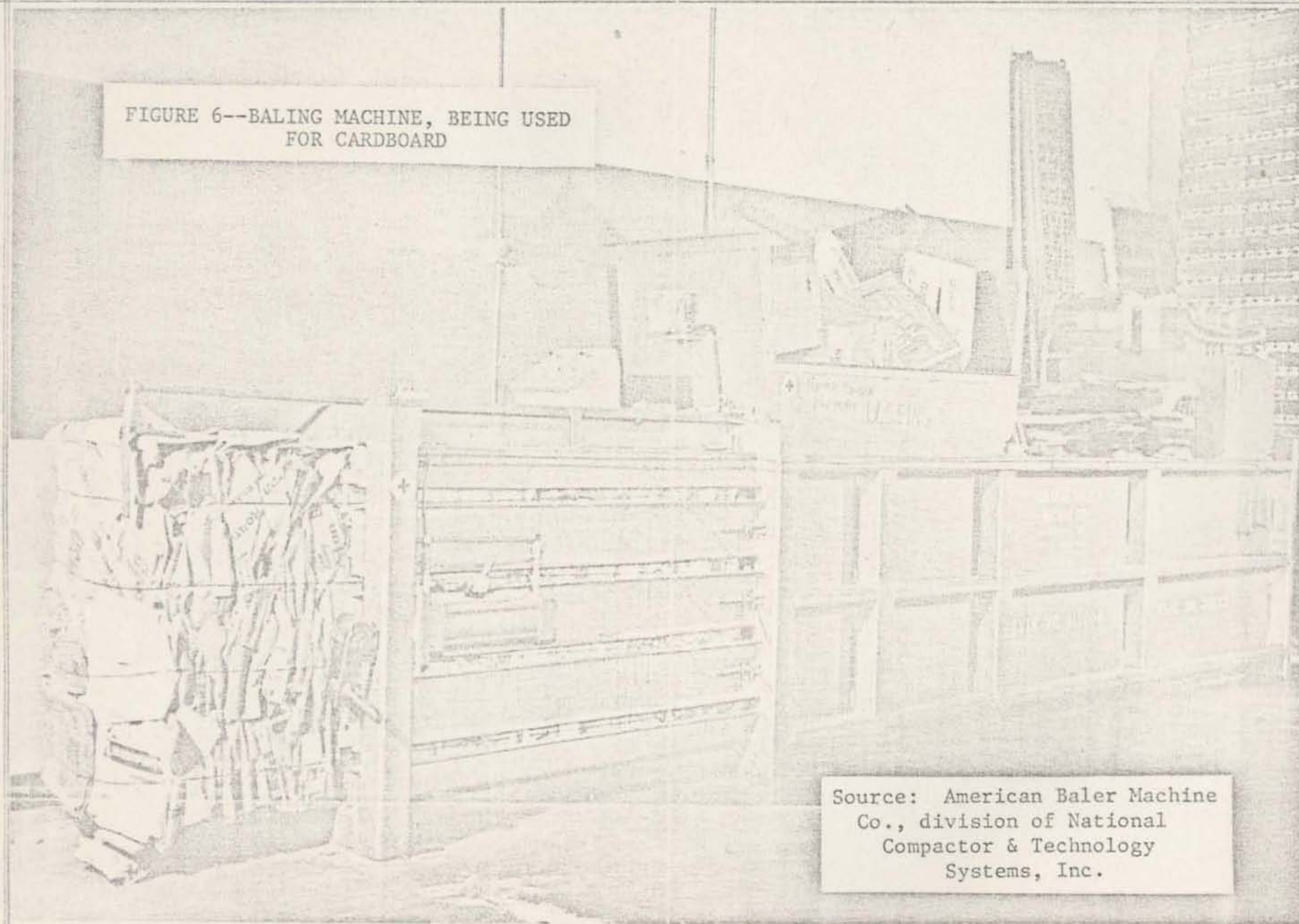
(Baling in its simplest form is the binding together of useful materials such as newspapers and bulk paper refuse. (See photograph, Figure 6.) More sophisticated techniques include the compression of refuse into blocks which can be coated and used as building blocks. The coating must be airtight to prevent the formation of methane gas inside the blocks and the resulting possibility of explosion.)

#### OPEN DUMPS

Although open dumps are still used extensively in Florida and throughout the nation, their number is diminishing as sanitary landfills and other methods become more widely used. Open dumps pollute the air through the burning of rubbish, and ground waters through leachate; they provide an environment suitable for rats, flies, and mosquitoes; they are unsightly and malodorous; they are a source of litter and a



FIGURE 6--BALING MACHINE, BEING USED  
FOR CARDBOARD



Source: American Baler Machine  
Co., division of National  
Compactor & Technology  
Systems, Inc.

place where explosions can occur. In short, the disadvantages of open dumps constitute the advantages of sanitary landfills. The open dump is a very cheap method for the disposal of solid wastes, but the practice no longer meets health and pollution standards set by the Federal Government and the states (20).

#### OCEAN DISPOSAL

Although ocean dumping is a relatively cheap means of disposing of solid wastes, it has major disadvantages: it is an ecologically poor practice, and it is cheap only as long as transportation costs are low. Most local and state agencies prohibit this practice.

Direct costs of ocean disposal of bulk material, excluding collection, transportation, and indirect environmental costs, are \$1 to \$10 per ton. Direct costs for baled, barreled, or otherwise contained material are \$7 to \$50 per ton at dockside (14).



#### IV. EVALUATION OF SYSTEMS FOR FTU

##### GENERAL

Many solid waste systems are available for use at FTU; however, some systems can be eliminated at the outset because of obvious major drawbacks. Ocean dispersal will not be used because the one-way haul distance to the ocean is about 50 miles (high cost), and the waters there (Brevard County) are used extensively for fishing and swimming. The waters are fished, both privately and commercially, for at least 35 miles off the coast.

An open dump is unsuitable for the University for ecological and aesthetic reasons as well as for nonconformance with state health and pollution standards. As FTU grows and the campus population density increases, the arguments against open dumps will gain even more validity.

Pyrolysis has high operating costs and must be teamed with other processes, making the complete system quite expensive. But its greatest deficiency may be that there is still reasonable doubt about its day-by-day operational capabilities. Pyrolysis is an advantageous technique for disposing of plastic and rubber wastes, which present difficulties for other disposal methods. However, the percentage of plastic and rubber in FTU solid waste is low (all of the nonpaper, nonmetal waste is estimated to constitute only 9 percent of the total FTU refuse). Therefore, this advantage of pyrolysis is lost on the

high paper content of FTU refuse. Although a few pyrolysis units have operated successfully in the United States, no major pyrolysis facilities have been built thus far for municipalities. The city of Mount Vernon, New York, plans to construct a demonstration plant of 150 tons/day capacity (21). Implementation of pyrolysis at FTU should await the availability of operational data from such a demonstration plant.

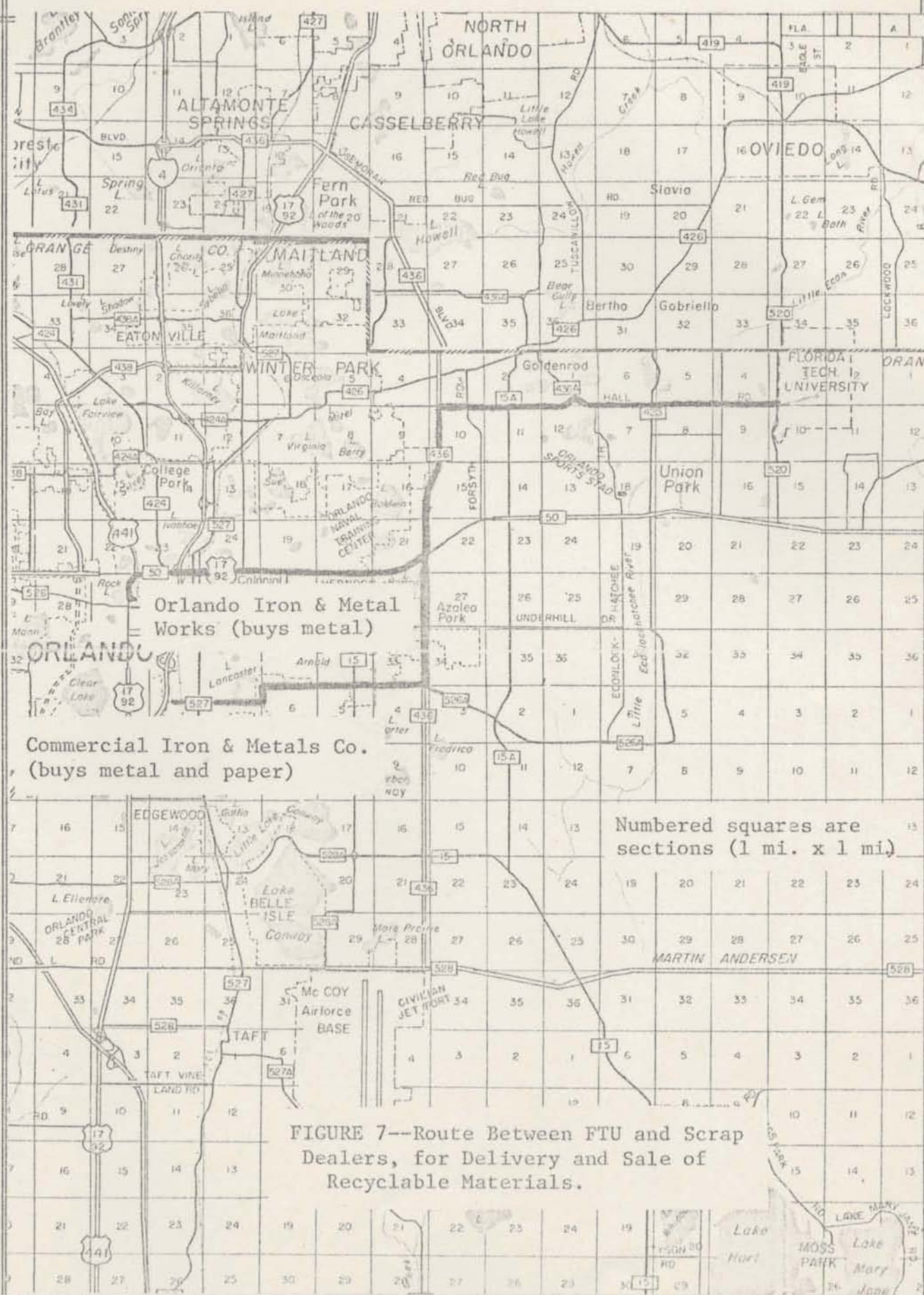
Pyrolysis, ocean dispersal, and open dumps are eliminated from further consideration as suitable methods of solid waste disposal at FTU. An evaluation follows, of each of the six systems remaining under consideration.

#### RECYCLING AT FTU

A 1971 study of the FTU solid waste disposal system (4) concluded that the most economical system for FTU was one wherein all waste was compacted and no waste was recycled. From an ecological standpoint, the most desirable system involved a combination of recycling of paper and aluminum cans with compaction of the remaining campus solid wastes. This alternative was considered the best ecologically because, of the alternatives considered, it had the greatest amount of recycling. Both the economical and the ecological plans had operational costs that were lower than the existing system of waste pickup by fourteen Dempster Dumpsters.

At the present time, there are two commercial enterprises in Orlando that buy non-industrial scrap metals (see map, Figure 7):





Orlando Iron & Metal Works  
1219 W. Robinson Avenue

Commercial Iron & Metals Company  
415 W. Kaley Avenue

Commercial Iron & Metals Company also buys scrap paper (under the name Commercial Paper Stock) at 1840 S. Division--across the street from the W. Kaley address. The Sandroni Scrap Metals Company of 310 E. New Hampshire Street buys industrial scrap metals only and is not considered as a marketplace for FTU waste metals. There is no buyer for used glass in Orlando. There are three reclamation centers for glass in Florida, the nearest to FTU being in Lakeland. The cost of transporting glass to Lakeland (65 miles from FTU) is greater than the return from the glass (about \$20 per ton). (22).

Orlando Iron & Metals Company, 15½ miles from FTU, currently pays 6¢/lb. for all-aluminum cans and 60¢/100 lbs. for scrap iron. Commercial Iron & Metals Company, 17 miles from FTU, pays 5¢/lb. for all-aluminum cans and 40¢ to 80¢/100 lbs. for other scrap metals. Neither concern is buying "tin" cans (steel cans coated with tin) at the present time. Current prices for scrap paper at the one available marketplace are 35¢/100 lbs. for newspaper and \$20/net ton for computer cards. There is no market for mixed paper (any paper except newspapers and computer cards) at the present time. Current prices are summarized as follows:

	\$/ton
Aluminum at 6¢/lb.	120
Computer cards at \$20/ton	20
Scrap iron at 40¢ to 80¢/100 lbs.	8 to 16
Newspaper at 35¢/100 lbs.	7



Recycling must be evaluated not only on the basis of technical feasibility, but also on the market potential of a product, projected revenue from sale of products, capital costs, etc. Concern, Incorporated, an organization interested in recycling and ecology, advises those who are considering the collection of materials for recycling to "be absolutely sure that there is a market for the material you collect. It will be a frustrating experience if the market for newspaper, for example, is glutted and your collection ends up in a landfill or an incinerator." (23). This good advice, plus the present market conditions can be taken as criteria for deciding which items (if any) should be collected at FTU for recycling at the present time. Therefore, the only materials that will be considered for current recycling are newspapers, computer cards, all-aluminum items, and other scrap metals. For future recycling, this study will also consider that a market may exist for mixed paper, the average price to be 15¢/100 lbs. for pickup service at FTU.

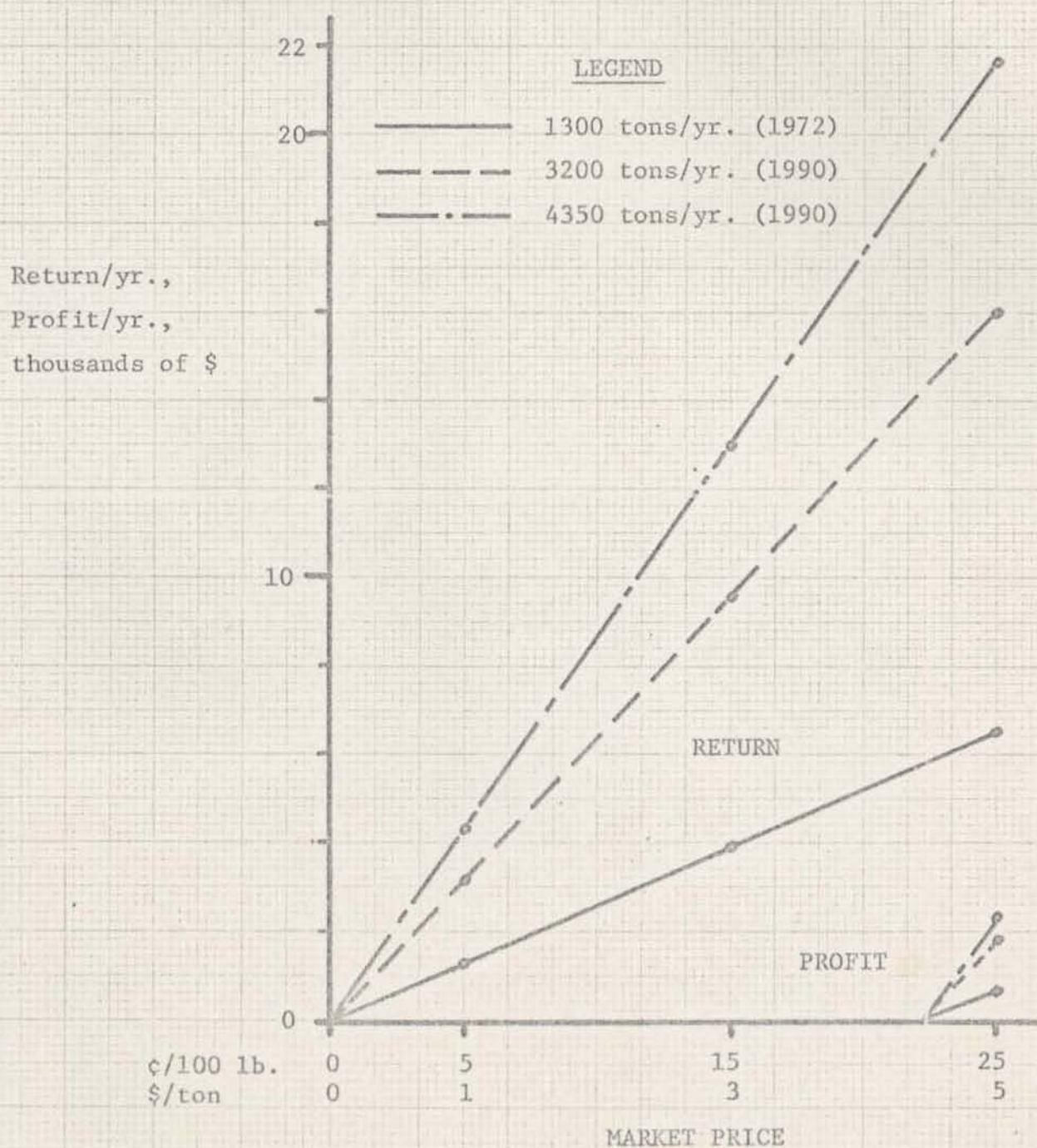
The fact that 90 percent of FTU solid waste is paper would indicate that recycling would be advantageous as a method of disposal. However, market conditions and the composition of FTU waste paper impose constraints. Currently, there is a market for newspapers and computer cards, but only about 10 percent of FTU waste paper is newspapers, and Computer Center purchase records indicate that computer cards constitute only 0.1 percent of total FTU refuse. Thus only 144 tons per year of newspapers are currently available for collection and sale, and a mere 1.6 tons per year of computer cards can be recycled. Records from FTU Auxiliary Services indicate that the amount of

all-aluminum in FTU refuse is also very small--about 0.25% of total refuse. Thus the total market value of FTU paper currently is about \$1030, aluminum would bring approximately \$480, and other metals, \$100. From the total possible income of approximately \$1610 per year must be deducted the cost of transportation between FTU and the commercial scrap dealers. Assuming that a 1 1/2-ton truck (fully loaded) is used to deliver the scrap materials to market, the total transportation costs would approximate \$192 per year. Labor costs for 27 to 28 trips per year to the scrap dealers would be about \$1088 per year, leaving \$330 profit if other costs are not considered. Such costs would include: the labor cost of segregating those marketable materials that were not segregated at the source, e.g., by individuals discarding their all-aluminum cans in receptacles marked for that item; the initial and operating costs of maintaining an on-campus collection center; and the transportation and labor costs of transferring the material from the trash receptacles to the campus collection center. These costs are not estimated here but are mentioned to show that recycling profit, for the present FTU population and for today's market, would be less than \$330 per year.

Should a market for mixed paper develop in the near future, FTU could sell about 1300 tons per year. Commercial Paper Stock Company has offered (in 1971) to pick up mixed paper at the campus and pay 15¢/100 lbs., when there is a market for mixed paper. Commercial Paper Stock would use a truck with a load capacity of 27,000 lbs., thus minimizing transportation costs. The return on thirteen tons per year, for prices of 5¢ to 25¢/100 lbs., is shown on Figure 8. At 15¢/100 lbs.



FIGURE 8--REVENUE AND PROFIT FROM SALE OF MIXED PAPER,  
PICKED UP ON CAMPUS BY COMMERCIAL DEALER



the return of \$3900/yr. would be more than canceled by the cost of labor to load the Commercial truck 96 times per year. The "profit" would be an estimated deficit of \$1870/year. At 25¢/100 lbs., a profit of \$720/year could be realized. For the estimated labor costs of \$5760 per year, the break-even selling price of mixed paper would be 23¢/100 lbs. Again, this does not include the labor costs of segregation of the paper, costs of implementing and maintaining an on-campus collection center, and labor and transportation costs of transferring the paper from the trash receptacles to the campus collection center.

At the estimated peak population of 20,000 to 27,000, the amount of generated solid wastes will be 7.9 to 10.7 million pounds per year. At current market prices, sale of the aluminum, other scrap metals, newspapers, and computer cards would result in profits of \$665 to \$994 per year. As with the figures for 1972, the "profit" on mixed paper would be a deficit (as much as \$15,000 per year) unless the paper were sold at or above the estimated break-even price of 23¢/100 lbs. At a price of 25¢/100 lbs., mixed paper would return a profit of \$1800 to \$2400/year, depending on the FTU population (20,000 to 27,000). The estimated potential profits from recycling are summarized on Table 2.

The profit figures that have been calculated are sensitive to changes in truck size and labor costs. Field experience in loading a truck with mixed paper may show that labor costs differ from those estimated, and that the break-even sale price is other than 23¢/100 lbs. However, the profit figures do indicate that recycling is not feasible



TABLE 2--SUMMARY OF REVENUE AND PROFIT FROM  
RECYCLING AT FTU

<u>1972</u>	<u>\$/ton</u>	<u>Tons/yr.</u>	<u>Revenue/yr.</u>	<u>Profit/yr.*</u>
Newspapers	7	144	\$ 1,000	--
Computer Cards	20	1.6	30	--
Aluminum	120	4	480	--
Other Metals	~12	8	100	--
Total		149.6	\$ 1,610	\$ 330
Mixed Paper	1	1300	\$ 1,300	-\$ 4,470
	3	1300	3,900	- 1,870
	5	1300	6,480	+ 720
<u>1990</u>				
Newspapers	7	355/481**	\$ 2,480/3,470	--
Computer Cards	20	4/5	80/108	--
Aluminum	120	10/13	1,190/1,610	--
Other Metals	~12	20/27	237/322	--
Total		389/526	\$ 3,987/5,510	\$ 665/994
Mixed Paper	1	3200/4300	\$ 3,200/4,300	-\$11,000/-15,000
	3	" "	9,600/13,000	- 4,600/-6,280
	5	" "	16,000/21,700	+ 1,800/+2,400

\*Does not consider costs of segregating materials, initial and operating costs of maintaining an on-campus collection center, and transportation and labor costs of transferring the material from the trash receptacles to the campus collection center.

\*\*Numbers with slashes are for FTU populations of 20,000/27,000.

at FTU at the current prices. Even if mixed paper were not recycled, a "profit" of only \$330 per year would not be worth the effort of establishing and maintaining a recycling collection center; educating the campus population about recycling; segregating newspapers, computer cards, aluminum, and other metals; and transporting the materials to the on-campus collection center and subsequently to the scrap dealers. By 1990, the "profit" could be \$994 annually from newspapers, computer cards, aluminum, and other metals. However, the segregation and transportation costs would be greater, and implementation of a recycling program would require even more effort than in 1972 because of the greater FTU population and greater volume of refuse.

The decision to segregate and store mixed paper for recycling should be made on the basis of field experience with loading of the paper on trucks (to establish accurate labor costs) and on the basis of existing and probable market conditions. The cost of loading the trucks could be close to zero if the labor could be performed by interested student organizations as a non-cost project. If student organizations could perform this service, recycling of mixed paper at FTU might be economically feasible.

#### INCINERATION AT FTU

As an example of the costs of an incinerator to meet FTU's current needs, one unit available through an Orlando firm sells for \$33,710, (24) plus optional equipment, installation, land, etc. The unit has an afterburner that is claimed to reduce significantly smoke, odors, and fly ash. The weight of pollutants is reportedly less than six percent of the allowable amount.



To incinerate FTU's solid wastes in 1990, a unit costing about \$120,000 (at today's prices) would be required. The calculations for the design of such an incinerator (20 tons/day) are included in Appendix.

Advantages of incineration at FTU are:

The avoidance of the leachate problem that can be present with a sanitary landfill. The small amount of residue from an incinerator is inert.

Because the campus is not located in a polluted industrialized area, the small amount of stack gas pollutants emitted by an incinerator with air pollution controls would not contribute to a local pollution problem. The rural setting that FTU enjoys would allow rapid dissipation of stack gases.

Incineration of FTU's solid wastes would eliminate the need to transport the wastes elsewhere (unless recycling were part of the disposal system). This would save the cost of \$7,200 per year (in 1971) charged by Dump All, Incorporated, for refuse collection (4).

The disadvantages of incineration at FTU are the disadvantages of incineration anywhere: large capital investment and high operating costs. Even if a trade-off study indicated that a \$120,000 capital investment were justified on the basis of savings from elimination of the commercial refuse collection service, the high cost of operations would remain as a strong factor against incineration. At the maximum estimated FTU population and at \$5 per ton processed, operating costs would be about \$27,000 per year.

### COMPOSTING AT FTU

Experience with composting in the United States has shown that this generally expensive process is usually accompanied by a marked inability to sell much of the product. Unless FTU could find or develop a market for composted material, a campus composting system would be an expensive way of reducing the volume of refuse by about 50 percent. The aesthetic and odor factors of a composting system are valid arguments against composting on campus.

Efficient composting requires that grinding (milling) be a part of the system in order to facilitate handling, digestion, and mixing of the materials. This increases system costs, as discussed in a subsequent section, "Combination Systems at FTU."

Although the cost of composting may not decrease in the future, composting should be periodically evaluated with respect to competing systems. Composting would tend to become more desirable as sanitary landfills become filled and other landfill sites become scarce, and as more stringent air pollution regulations increase the cost of incinerators.

For FTU, however, the primary consideration regarding composting is the availability of a market for composted materials. Should a market be available, the composting process, including a degree of recycling, could become a practicable method of disposing of FTU solid wastes.



#### SANITARY LANDFILL AT FTU

FTU property consists of 1,227 acres (about  $1\frac{1}{2}$  by  $1\frac{1}{4}$  miles), of which about 70 percent is planned for development (see Figure 9, Master Plan superimposed on topographic map). Most of the area to the east of the planned development will be left in the natural state.

On the basis of one acre per year per 10,000 people for a landfill with seven feet of compacted refuse, a maximum of only 36 acres would be needed for landfill requirements up to 1990; then a maximum of 27 acres per decade would suffice. Thus the acreage requirement is not a problem.

The water table is a different matter. Test borings made before the land was accepted for use as a University site disclosed a very high water table. At the Science Building location, the table was at eight inches. It was also discovered that an underground stream runs north from Lake Lee to Lake Claire. Since the pH of the water was about four to four and a half, the high water table presented a serious problem. That problem has been resolved by an extensive system of French drains (perforated pipe about six feet below the surface) that encircles the portion of the campus planned for development. Water from the French drains flows into storm sewers that take the water to an "ecological area" shown on the contour map (see Figure 9) as marshland. This system has lowered the water table below the developed part of the campus by about seven feet. At the "ecological area," the quantity of water waiting to drain eastward to the

FIGURE 9--FTU MASTER PLAN ON TOPOGRAPHIC MAP, SHOWS LAND ELEVATIONS IN RELATION TO CAMPUS DEVELOPMENT.





Econlockhatchee River provides a water table that is essentially at the elevation of the marshland (25). Therefore, about half of the undeveloped eastern portion of the FTU property (the southeastern half) is marshland unsuitable as a site for a sanitary landfill. The other half of the eastern part of the property (northeastern half) is poorly suited for an economical landfill operation; the remote ground (northeast corner) is low, while the high ground is at or near an area planned for future housing. The high ground in the southwestern part of the property is likewise planned for a student and faculty housing area.

In summary, FTU has more than enough land for a sanitary landfill to satisfy its needs through and beyond the year 2000. However, the land that might be used is low, with a high water table.

If the Master Plan is not developed, and campus growth stops before buildings are erected on all of the high ground, a site at 70-feet elevation might be used for a sanitary landfill. The site is a quarter mile northeast of the geographical center of the University property, or a half mile northeast of the Science Building. However, it is assumed that campus growth will continue to 20,000 to 27,000 population and that the Master Plan will be implemented essentially as planned.

#### MILLING AT FTU

Hammermills for handling metal can generate intolerable noises. For use at FTU, it would be necessary to isolate such equipment in a

corner of the campus and to take measures to minimize the noise level perceived at the populated portions of the campus. However, hammermills for the shredding of paper do not present a noise problem. Since metal constitutes less than one percent of campus solid wastes, considerations of campus milling will be confined to the 99 percent of non-metallic refuse.

The capital cost of milling equipment is high. For the current FTU population, a paper shredder would cost \$4,000, with the total installation costing about \$20,000, excluding land. For the estimated maximum FTU population, a shredder for paper would cost \$9,100. The total installation cost would be approximately \$41,000 excluding land (26).

Milling, like composting, is not a complete disposal method. About half of the original volume remains after the process is complete. Therefore, milling at FTU would be done only in conjunction with another method and would increase both the efficiency and the cost of the over-all disposal system.

#### COMPACTING AND BALING AT FTU

As is true of milling, compaction or compaction plus baling is not a complete system of solid waste disposal. Paper could be compacted and baled to minimize required storage space and provide ease of handling before being taken off-campus for recycling. FTU refuse could be compacted to minimize storage space required and to lower the cost of refuse collection by the contractor. These and



other compaction alternatives reportedly would have saved in 1971 up to \$2285 as compared with the existing system of refuse pickup by a contractor (4).

An institutional compactor that could handle all of the present load of FTU solid wastes and half of the maximum future load sells for about \$4200 (27).

A baler that could easily handle all of the current load of FTU paper sells for \$4150. A baler with sufficient capacity for the estimated maximum paper load in 1990 has a cost of \$9365 (28). In this instance, the least expensive method of obtaining baling capability might be to purchase a baler now for \$4150 and buy a similar unit some five years from now.

#### COMBINATION SYSTEMS AT FTU

Cost information for all of the disposal systems considered for FTU is summarized in Table 3. The dollar values were taken from many different sources and should be viewed only as representative figures.

As stated at the beginning of Section IV, three of the nine systems considered could be discarded at the outset because of major disadvantages. Of the remaining six systems, only the sanitary landfill is a complete disposal system. Incineration is virtually complete, requiring only the disposal of residue and quench water. These inert materials (residue plus some inert fraction in the quench water) can easily be disposed of in a miniature landfill on campus, or transported to a county sanitary landfill.

TABLE 3--COST SUMMARY OF SOLID WASTE DISPOSAL SYSTEMS  
FOR FTU'S MAXIMUM POPULATION

<u>System</u>	<u>Equipment Capital Cost</u>	<u>Operating Cost/ton</u>	<u>Remarks</u>
Recycling	\$ 5,000	\$ 5	Yields revenue. Market uncertain.
Incineration	120,000	Up to 12	Residue.
Pyrolysis	Unknown	Unknown	Residue.
Composting	400,000	Up to 20	Yields revenue. Market unlikely. Residue.
Sanitary Landfill	15,000	Up to 2	FTU land marginal.
Milling	41,000		A partial system.
Compacting	8,400		A partial system.
Baling	8,300		A partial system.
Open Dump	-	-	Illegal.
Ocean Dispersal	-	-	Ecologically unsound.



The six systems can be combined in many ways. Some of the workable possibilities are:

Recycling + Incineration

(recycling of mixed paper, if feasible, followed by incineration of the remaining refuse)

Recycling + Sanitary Landfill

(recycling of mixed paper, if feasible, followed by sanitary landfilling for the remaining refuse)

Either of the above combinations + Milling

(recycling of mixed paper, if feasible, followed by milling of the remaining refuse, followed by incineration or landfilling of the material milled)

Recycling + Milling + Composting

(recycling of mixed paper, if feasible, followed by milling of the remaining refuse, followed by segregation and disposal of noncompostable materials, followed by composting of the remaining refuse)

Compacting with or without Baling + Contractor Refuse Service

(compacting all campus refuse or compacting and baling all campus refuse, followed by pickup of all refuse by the contractor refuse collection service)

Compacting with or without Baling + any of the Recycling Alternatives

(segregation, compacting, and baling of marketable paper; followed by recycling of the compacted/baled paper; possibly followed by milling of the remaining refuse; followed by incineration or landfilling)

For any of the combination systems, capital costs are essentially additive. For example, for a system of compacting + recycling + milling + composting, it would only be economically sound to provide compacting equipment to handle all of the mixed paper that might be recycled. Compaction of mixed paper would account for an estimated 81 percent by weight of all campus refuse. The campus collection center would be built to accommodate the total volume of all mixed paper. (The

collection center would probably not be built if FTU were to decide against ever collecting mixed paper for recycling.) The milling equipment should have the capacity to take all of the campus refuse in order to allow for a possible collapse in the market for mixed paper. It follows that the composting system should have the capability of processing all of the milled material except the small amount of noncompostable items. Since milling reduces the volume by about 50 percent, the composting capacity need be only half of the milling capacity.

Although capital costs of combined systems tend to be additive, operating costs may or may not be. Collection and sale of all mixed paper would tend to result in lower operating costs for a sanitary landfill, for example, since some 81 percent of the refuse would never reach the landfill.

The tendency for the cost of combined systems to be additive does not mean that the profit from them will necessarily be lower. For a combined system of milling + sanitary landfill, the annual profit will be less than from a sanitary landfill alone, but the life of the landfill may be extended by 40 percent. ("Profit" here refers to the savings of one disposal method over another.) For any combined system involving the successful processing and sale of significant amounts of recyclable or compostable materials, the profit of the combined system will probably be much greater than the "profit" of



one of the individual systems. Thus recycling + incineration would provide more profit than incineration alone.

## V. SUMMARY AND CONCLUSIONS

Of the nine systems originally considered for disposal of solid wastes at FTU, three were eliminated from further consideration because of major deficiencies (the three are ocean dispersal, open dumping, and pyrolysis). Each of the remaining six systems was evaluated in the context of the FTU environment. The basic constraints for the evaluations were considered to be the University budget, the various pollution control regulations, and the environmental well-being of the campus (control of odor, noise, etc.).

### RECOMMENDATIONS

It is recommended that no recycling be done at the current market prices, but that a small field study be performed to determine the labor costs of recycling mixed paper (as opposed to computer cards and newspapers) and to establish a break-even market price. This study should be followed by a monitoring of the market dollar value of mixed paper, with recycling being instituted when the market price is near or above the break-even point.

It is concluded that, from an economical standpoint, the only other suitable disposal systems are sanitary landfill and the existing system (contractor refuse collection) with or without compacting.

From an environmental standpoint, the most favorable systems at FTU (assuming recycling is implemented) are incineration, milling +



composting, and the existing system, with sanitary landfill being acceptable only if a remote site with low water table could be used. A study should be made to evaluate possible on-campus sites for a sanitary landfill, as a hedge against termination of the present arrangement with Dump All, Incorporated.

On the basis that the University Master Plan is implemented and a remote and dry site cannot be found on campus for a sanitary landfill, and that a sizable market for composted materials does not reveal itself, it is recommended that those materials not recycled be collected by a contractor with a refuse collection service. If the study on mixed paper indicates the probability of a strong market for mixed paper, then purchase of a compactor is not recommended. However, if it is not economically profitable to sell mixed paper, then all refuse (except that recycled) should be compacted and collected by the contractor refuse collection service. In any event, any change in the number of Dumpsters used or the frequency of refuse pickup as a result of a decrease in refuse volume should be accompanied by a reevaluation of the fee paid the collection contractor. Both recycling and compaction could have a significant effect on refuse volume.

#### FUTURE NEEDS

If a suitable site can be found on campus for a sanitary landfill, and if a landfill operation becomes necessary, equipment will be needed to excavate, spread, compact, and cover--all of which could be done by a single caterpillar tractor.

Should the recycling of mixed paper become profitable (or at least, economically feasible), the campus would need a recycling collection center and a program to accomplish the collection. The collection center need be little more than a concrete slab with bins or other storage facilities, plus a roof and fence. Care should be taken to choose a site that minimizes the effects of noise and traffic congestion caused by trucks travelling between the collection center and the commercial scrap dealers.



APPENDIX

DESIGN CALCULATIONS FOR A 20-TON/DAY INCINERATOR  
WITH HEAT RECOVERY

# APPENDIX

## DESIGN CALCULATIONS FOR A 20-TON/DAY INCINERATOR WITH HEAT RECOVERY

### DESIGN CALCULATIONS

#### 1. Refuse Characteristics

Assume density of 500 lb./cu. yd.

Storage pit will hold  $\frac{(20 \text{ tons/day})(2000 \text{ lb./ton})}{500 \text{ lb./cu. yd.}} = 80 \text{ cu. yd.}$

#### 2. BTU Content of av. refuse: 8000 BTU/lb.

#### 3. Refuse Composition:

<u>Category</u>	<u>BTU/lb.(8)</u>	<u>% of Total Refuse</u>	<u>Adjusted BTU/lb.</u>
Paper	7900	90	7110
Mineral	negligible	3	0
Misc.*	7600	7	<u>530</u>
			7640

Assume: 5% moisture in the refuse.

10% ash

85% combustibles

BTU Content =  $(0.95)(7640) = 7258 \text{ BTU/lb.}$

#### 4. Heat Input:

$(7258 \text{ BTU/lb.})(20 \text{ tons/day})(2000 \text{ lb./ton})(\text{day}/24 \text{ hrs.})$

$= 12.1 \times 10^6 \text{ BTU/hr.}$

\*Includes garbage, plastics, wood, textiles, leather, rubber, ceramics, and glass. Nearly all of the FTU Cafeteria garbage goes through grinders into the sewer system. (29).



CALCULATIONS FOR BOTH A FIRE BRICK  
LINED AND WATER COOLED FURNACE

1. Combustibles:

Carbon + Hydrogen:

$$\begin{aligned} & (0.85)(20 \text{ tons/day})(\text{day}/24 \text{ hrs.}) \\ & = 0.71 \text{ tons/hr. or } 1420 \text{ lb./hr.} \end{aligned}$$

Water:

$$(0.05)(20/24) = 0.0416 \text{ tons/hr. or } 83.2 \text{ lb./hr.}$$

Ashes:

$$(0.10)(20/24) = 0.0833 \text{ tons/hr. or } 166.6 \text{ lb./hr.}$$

$$\text{Total Refuse Input} = 0.832 \text{ tons/hr. or } 1664 \text{ lb./hr.}$$

2. Estimates of combustible portion of refuse: (8)

$$\text{Carbon } 40.9/0.85 = 48.25\%$$

$$\text{Oxygen } 39.0/0.85 = 46.0\%$$

$$\text{Hydrogen } 4.88/0.85 = 5.75\%$$

$$\text{Sulphur negligible } 0\%$$

$$\text{Nitrogen negligible } 0\%$$

3. 4% of the combustibles (primarily carbon) will probably not be oxidized.

$$\begin{aligned} \text{Carbon oxidized} &= (0.96)(1420 \text{ lb./hr.})(0.4825) \\ &= 659 \text{ lb./hr.} \end{aligned}$$

$$\begin{aligned} \text{Carbon unoxidized} &= (0.04)(1420)(0.4825) \\ &= 27.4 \text{ lb./hr. of ashes} \end{aligned}$$

4. Percent hydrogen in bound water =

$$(46.0\% \text{ oxygen})(2 \text{ lb. hydrogen}/16 \text{ lb. oxygen}) = 5.75\%$$

5. Hydrogen available for combustion = (hydrogen in combustible refuse) - (hydrogen in bound water) =  $5.75 - 5.75 = 0\% = 0 \text{ lb/hr.}$

6. Bound water =  $(0.46 + 0.0575)(1420 \text{ lb./hr.}) = 735 \text{ lb./hr.}$

7. Total ashes =  $166.6 + 27.4 = 194 \text{ lb./hr.}$

Total inputs are:

<u>Refuse Constituent</u>	<u>lb./hr.</u>
Carbon.....	659
Hydrogen.....	0
Bound water.....	735
Ashes.....	194
Moisture.....	83.2

#### AIR REQUIREMENTS

1. 1 lb. carbon + 11.53 lb. air  $\rightarrow$  3.665 lb.  $\text{CO}_2$  + 8.865 lb. N  
 1 lb. hydrogen + 34.34 lb. air  $\rightarrow$  8.936 lb. water vapor  
 + 26.464 lb. N

Total air required is:

$$\text{Carbon: } (659 \text{ lb./hr.})(11.53 \text{ lb. air/lb. carbon})$$

$$= 7600$$

$$\text{Hydrogen:}$$

$$= \frac{0}{7600} \text{ lb./hr. of dry air}$$

2. Usually 100% excess air is required.

$$\text{Total Air} = 2 \times 7600 = 15,200 \text{ lb./hr. design}$$



3. Moisture added by air at  $80^{\circ}\text{F}$  and 60% relative humidity

$$= (0.132 \text{ lb./lb. air})(15,200 \text{ lb./hr.}) = 200 \text{ lb./hr.}$$

4. Moisture from quench water.

Assume: residue off grates is cooled to  $1200^{\circ}\text{F}$

specific heat = 0.25, cooled to  $150^{\circ}\text{F}$

ash + unburned carbon  $\approx 194 \text{ lb./hr.}$

fly ash up the stack = 6% of 194 = 12 lb./hr.

Residual =  $194 - 12 = 182 \text{ lb./hr.}$

Heat in residual =  $182(0.25)(1200 - 150) = 47,700 \text{ BTU/hr.}$

From Steam Tables (30), get 1102 BTU.lb., then

$$(47,700 \text{ BTU/hr.})/1102 \text{ BTU/lb.} = 43.4 \text{ lb./hr moisture}$$

5. A mass balance would determine whether the assumption of 100% excess was correct. If the mass balance did not agree within 1%, the excess air percentage should be adjusted and subsequent calculations repeated (an iterative process) until the mass balance agrees.

#### FURNACE TEMPERATURE

Use base of  $80^{\circ}\text{F}$ ; then determine heat losses.

1. For fire brick, heat loss  $\approx 1800 \text{ BTU/sq. ft. / hr.}$  (31)

Area of furnace  $\approx 200 \text{ sq. ft.}$

Heat loss =  $200(1800) = 360,000 \text{ BTU/hr.}$

2. Residue, assuming  $150^{\circ}\text{F}$  at disposal and spec. heat = 0.25:

$$(0.25)(182 \text{ lb./hr.})(150 - 80) = 3180 \text{ BTU/hr.}$$

## 3. Unburned Carbon:

Potential heat = 14,093 BTU/lb.

$(27.4 \text{ lb./hr.})(14,093 \text{ BTU/lb.}) = 386,000 \text{ BTU/hr.}$

4. Vaporization of the refuse moisture. From steam tables,  
1048.6 BTU required to vaporize 1 lb. of water at 80°F.

Bound water: 735 lb./hr.

Refuse moisture: 83.2

Air moisture: 200

Quench moisture: 43.4

1061.6 lb./hr.

Moisture =  $(1061.6 \text{ lb./hr.})(1048.6 \text{ BTU/lb.}) = 1.11 \times 10^6 \text{ BTU/hr.}$

## 5. Fly ash. Assume 1700°F and spec. heat of 0.25

$(0.25)(1700)(12 \text{ lb./hr.}) = 5100 \text{ BTU/hr.}$

## 6. Total heat loss = 360,000 BTU/hr.

3,180

386,000

1,110,000

5,100

1,864,280 =  $1.86 \times 10^6 \text{ BTU/hr.}$

7. Heat available =  $(12.1 - 1.86) \times 10^6 = 10.2 \times 10^6 \text{ BTU/hr.}$ 

## 8. Temperature

<u>Gas</u>	<u>Weight (lb./hr.)</u>	<u>Sp. Heat</u>	<u>Wt. x Sp. Heat</u>
CO <sub>2</sub>	2615	0.22	575
O <sub>2</sub>	1760	.25	440
N	17,520	.25	4,380
H <sub>2</sub> O	935	.50	<u>468</u>
			5,863



Furnace Temperature at 100% excess air =

$$\frac{10.2 \times 10^6}{0.005863 \times 10^6} = 1740^\circ \text{F}$$

#### FURNACE SIZE

Design based on heat release of 20,000 BTU/cu.ft. / hr.

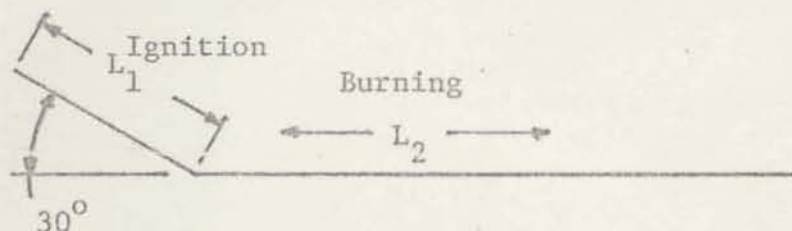
Grate Area Heat Release: 300,000 BTU/sq.ft. / hr.

Heat Input =  $12.1 \times 10^6$  BTU/hr.

Furnace Volume =  $(12.1 \times 10^6) / (20,000) = 605$  cu. ft.

Grate area =  $(12.1 \times 10^6) / (300,000) = 40$  sq. ft.

Furnace height =  $605 / 40 = 15.1$  ft.



Effective Grate Area = Ignition + Burning = 40 sq. ft.

Let  $L_1 = 16.5$  ft.

$L_2 = 40$  ft.

$W = 8$  ft.

then area =  $(16.5 + 40)(8) = 450$  sq. ft.

To maintain furnace volume despite loss due to grate slope, extend furnace four feet past burning grate (safety factor).

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